Multi-Dimensional, Non-Pyrolyzing Ablation Test Problems

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Abstract

Non-pyrolyzing carbonaceous materials represent a class of candidate material for hypersonic vehicle components providing both structural and thermal protection system capabilities. Two problems relevant to this technology are presented. The first considers the one-dimensional ablation of a carbon material subject to convective heating. The second considers two-dimensional conduction in a rectangular block subject to radiative heating. Surface thermochemistry for both problems includes finite-rate surface kinetics at low temperatures, diffusion limited ablation at intermediate temperatures, and vaporization at high temperatures.

The first problem requires the solution of both the steady-state thermal profile with respect to the ablating surface and the transient thermal history for a one-dimensional ablating planar slab with temperature dependent material properties. The slab frontface is convectively heated and also reradiates to a room temperature environment. The backface is adiabatic. The steady-state temperature profile and steady-state mass loss rate should be predicted. Time-dependent front and backface temperature, surface recession and recession rate along with the final temperature profile should be predicted for the time-dependent solution.

The second problem requires the solution for the transient temperature history for an ablating, two-dimensional rectangular solid with anisotropic, temperature dependent thermal properties. The frontface is radiatively heated, convectively cooled, and also reradiates to a room temperature environment. The backface and sidewalls are adiabatic. The solution should include the following 9 items: final surface recession profile, time-dependent temperature history of both the frontface and backface at both the centerline and sidewall, as well as the time-dependent surface recession and recession rate on the frontface at both the centerline and sidewall.

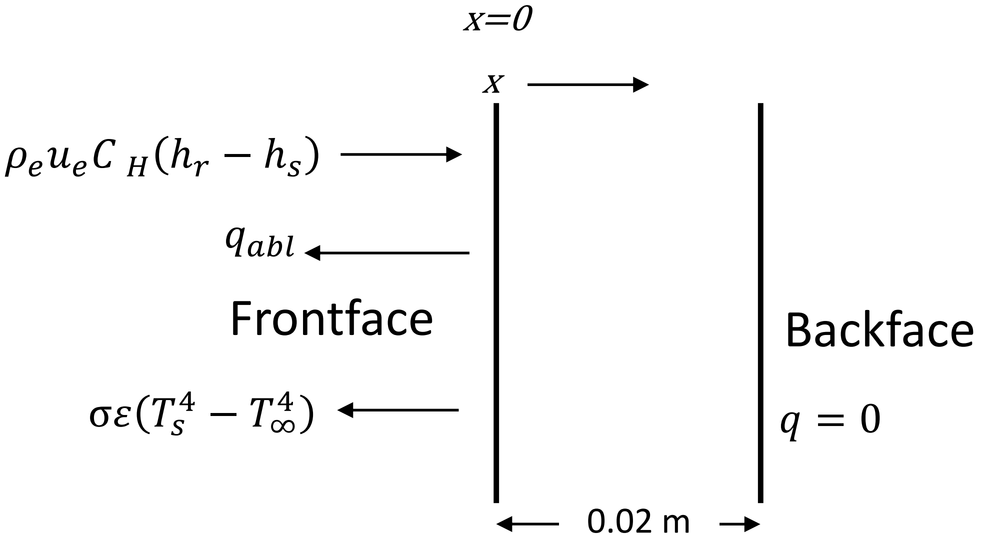
The results of the problems from all submitters will be collected, summarized, and presented at a later conference.

Background

- Non-pyrolyzing carbonaceous materials represent a class of candidate material for hypersonic vehicle components providing both structural and thermal protection system capabilities.
- Characteristics of non-pyrolyzing carbonaceous materials
  - No in-depth reactions, density is constant, modeling is less complex
  - High thermal conductivities, deeper thermal profiles
  - Anisotropic thermal conductivity, generally higher parallel to heated surface. Two-dimensional conduction can be very important.
  - Finite–rate surface kinetics can be important in the regimes encountered in hypersonic vehicles
  - Transport and thermodynamic properties are functions of temperature
- Test problems presented here are applicable to this class of materials and are described in detail in separate document

Test Problem 1 – 1-D Planar Slab

The geometry consists of planar slab with a thickness of 0.02 m (2 cm).

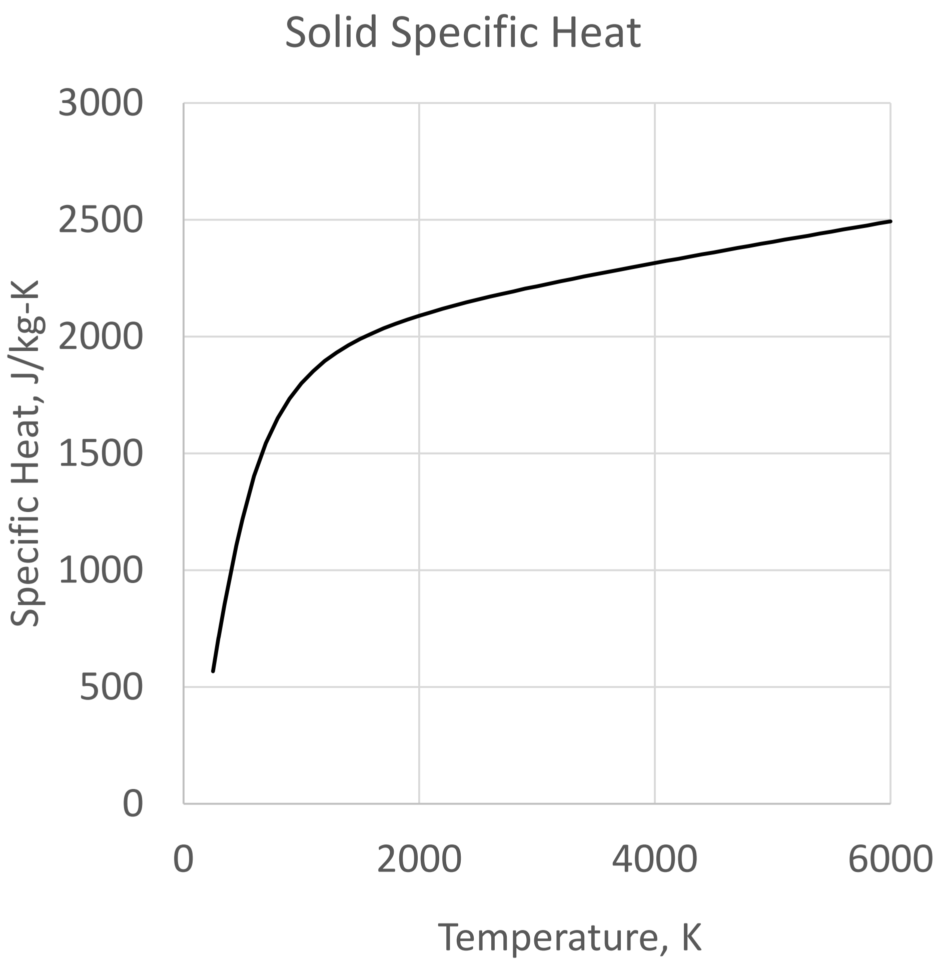


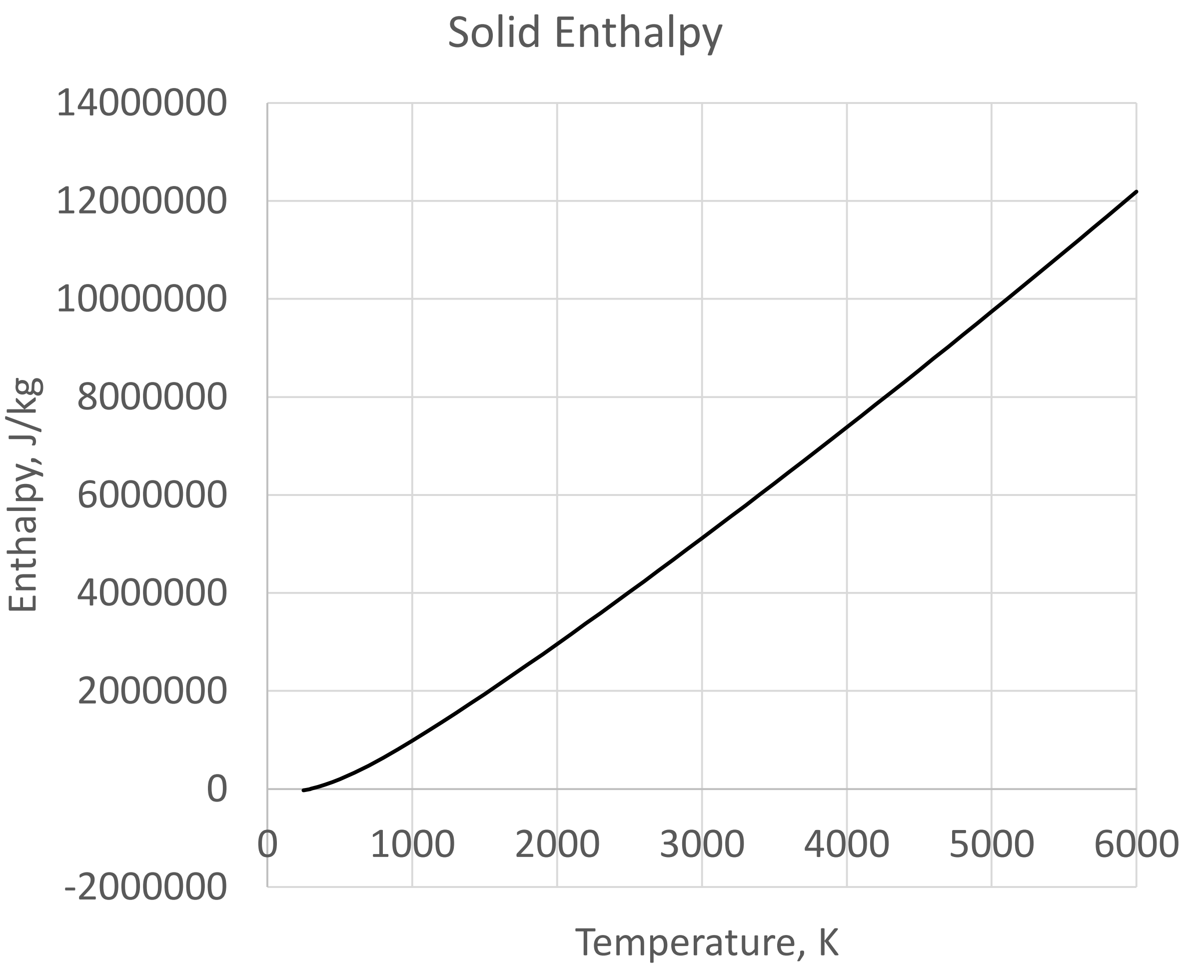
$$0\ s < t <= 60\ s, h_r = 40\ \text{MJ/kg}$$

$$60\ s < t <= 200\ s, h_r = 0\ \text{MJ/kg}$$

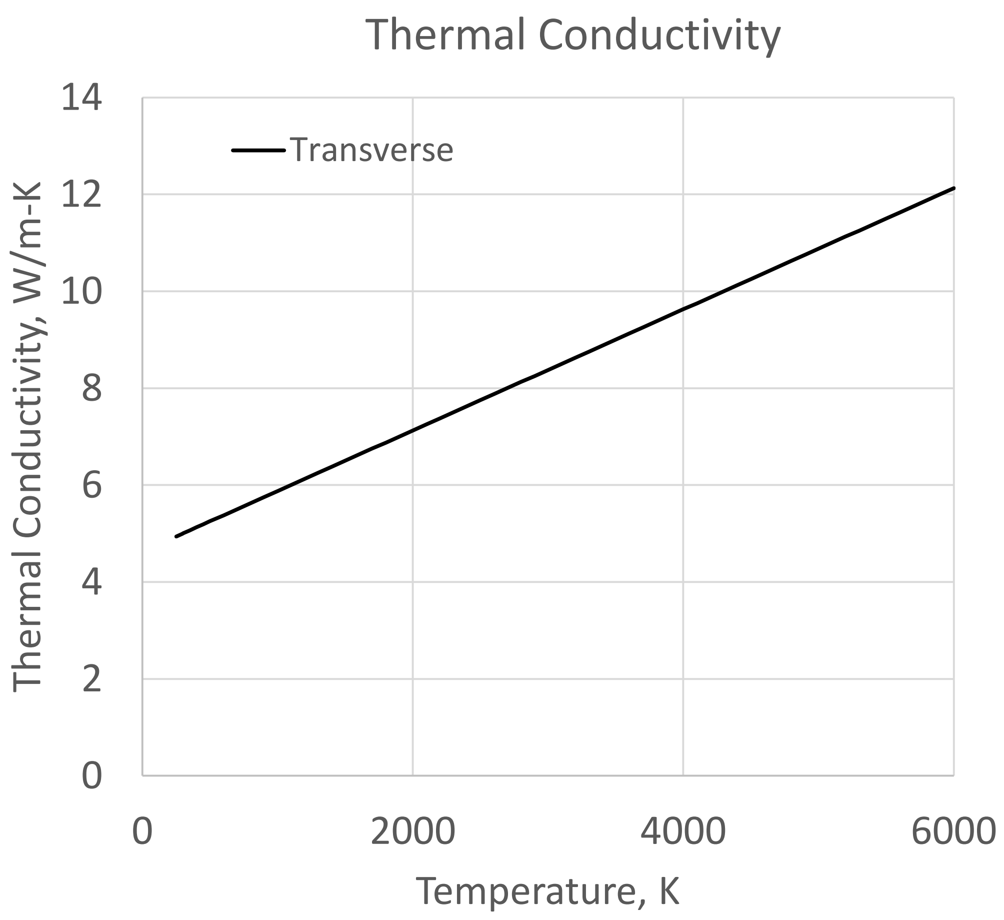
- Frontface convective heating and reradiation with ablation
- Backface adiabatic
- Item 1a – Steady-state problem
  - Temperature profile and steady-state mass loss
- Item 1b – Transient problem
  - Front and backface temperature history and surface recession and recession rate
  - Final temperature profile

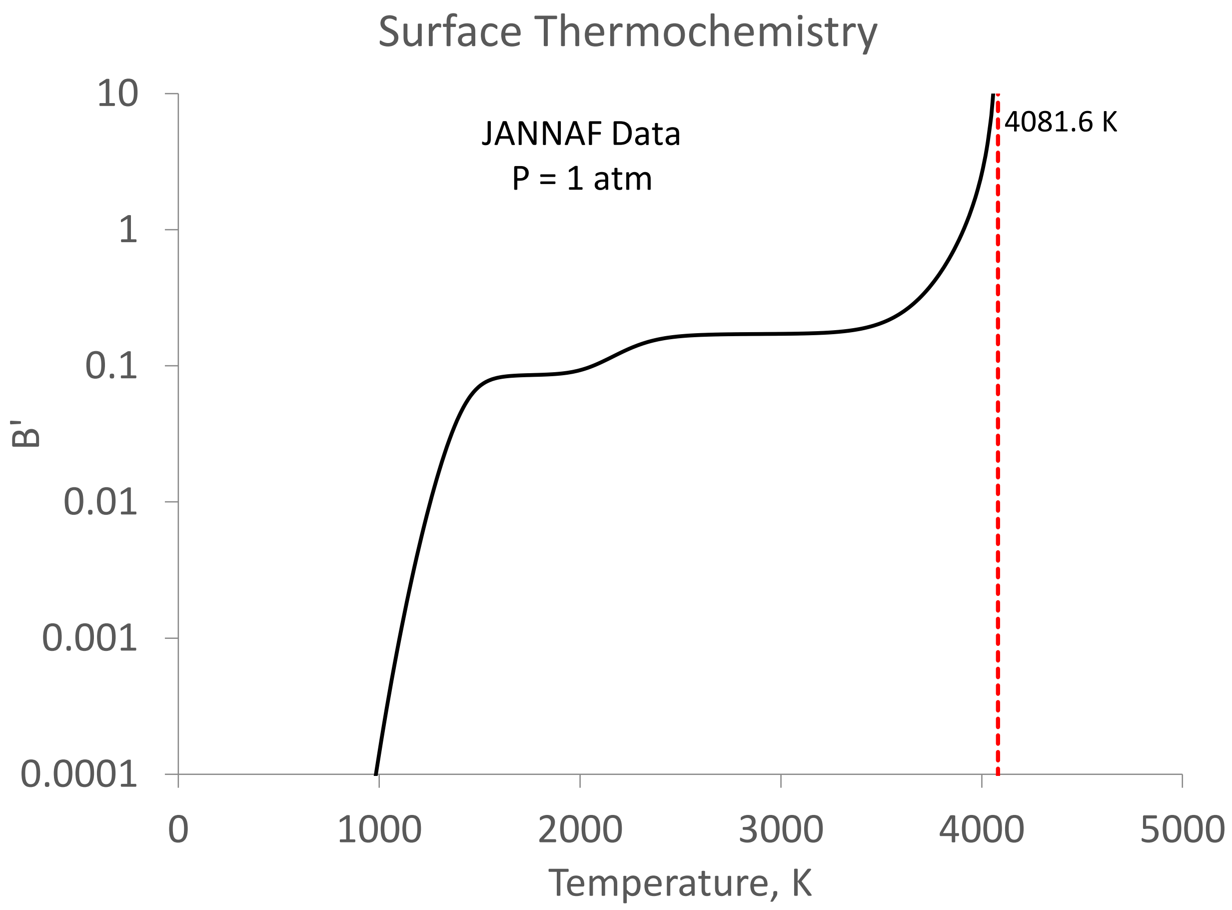
Problem 1 Material Properties - 1





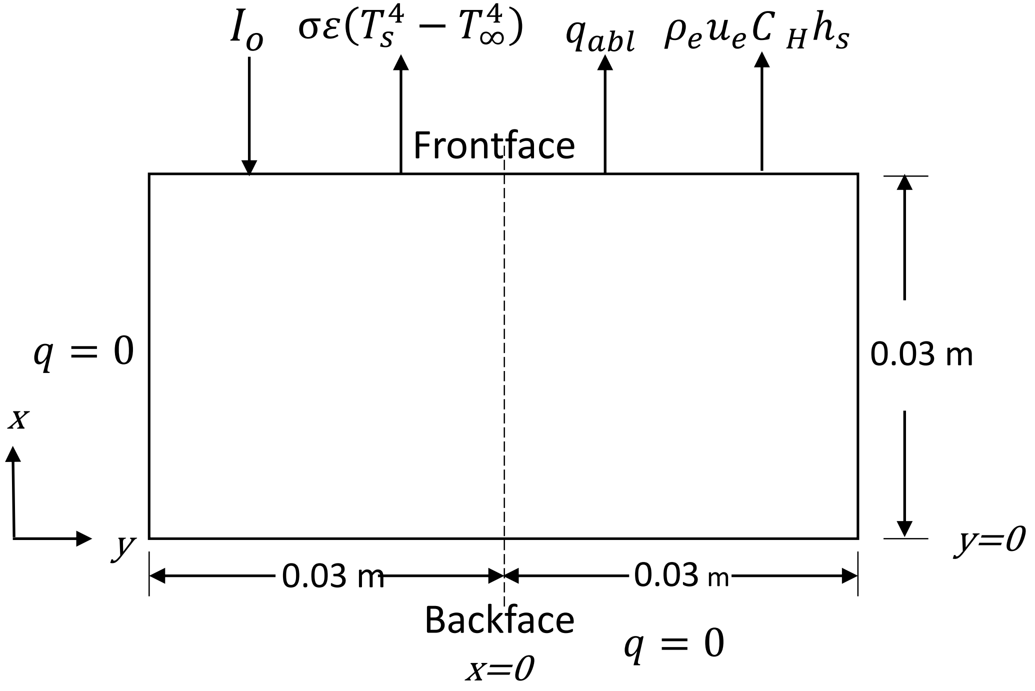
Problem 1 Material Properties - 2





Test Problem 2 – 2-D Rectangle

The geometry consists of rectangular slab with a width of 0.06 m (6 cm) and thickness of 0.03 m (3 cm). The slab is symmetric around the y-axis ($x=0$).

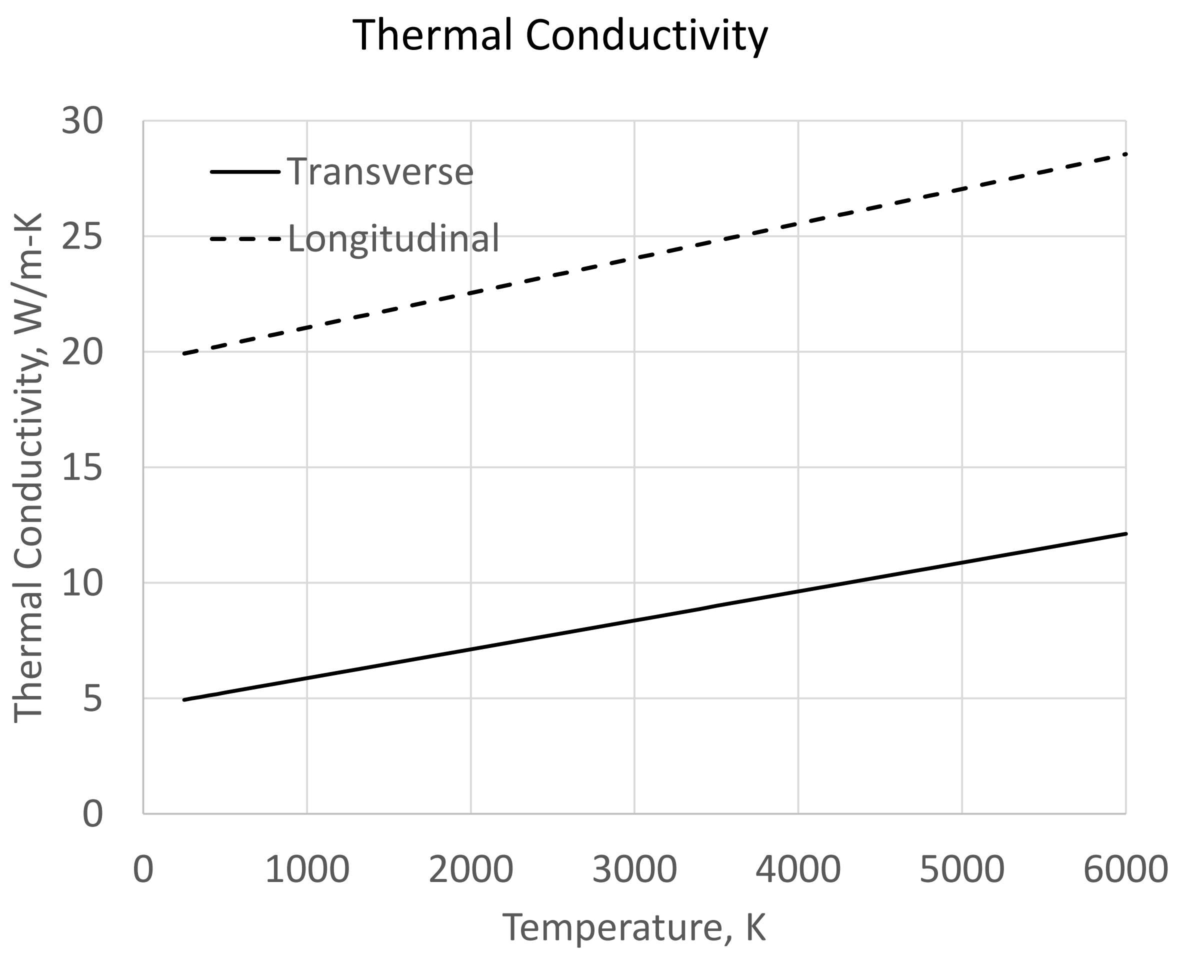


$$0\ \mathrm{s} < t <= 60\ \mathrm{s}, I_o = 3 \times 10^7\ \mathrm{W/m^2}$$

$$60\ \mathrm{s} < t <= 120\ \mathrm{s}, I_0 = 0\ \mathrm{W/m^2}$$

- Frontface radiative heating, convective cooling, and reradiation with ablation
- Backface and sidewalls adiabatic
- Item 1 – Transient problem
  - Front and backface centerline temperature, surface recession, and recession rate history
  - Surface recession profile
  - Sidewall temperature, recession, and recession rate history
  - Final sidewall and backface temperatures

Problem 2 Material Properties - 1



Specific heat, solid enthalpy, and surface thermochemistry same as Problem 1.

Result Submission Format

Please provide results for comparison in tab delimited text files with no headings.

Format of file contents described in detailed problem statements available separately

For the filenames, please use the following format:

ProblemZ_ItemX_ZZZ.txt

where Z is the problem number, X is the item number described in the problem statements, and ZZZ are the three initials of the primary author.